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Absorption length, radiation hardness and ageing of different optical glues

Th. Kirn, M. Häring, D. Schmitz, W. Schulz

I. Physikalisches Institut RWTH Aachen, 52056 Aachen, Germany

Abstract

We have tested different glues, which are candidates for coupling the APDs to the crystals. Results on absorption lengths before and after gamma-, neutron- and proton-irradiation are given. In addition we report on ageing tests for selected glues and Hamamatsu APDs in contact with the glue.

1 Introduction

The barrel part of the CMS electromagnetic calorimeter will consist of $\sim$60000 $PbWO_4$ (PWO) crystals which will be readout by Avalanche Photodiodes (APD) [1]. PWO emits its scintillation light in the wavelength region of 350 nm to 550 nm. It is a birefringent scintillator with relatively low light yield (50 photons/MeV) and with a refractive index close to 2.3 (wavelength region 380-500 nm)[2]. The number of photons detected by the APDs strongly depends on the coupling medium (glue) between PWO and APD. The index of refraction n_{glue} determines the angle of total reflection Θ_{TR} and the reflection losses in the transitions crystal to glue and glue to APD. Both effects influence the light collection efficiency with the optimum reached at $n_{glue} \approx \sqrt{n_{PWO} \cdot n_{APD}}$. In addition the absorption length of the coupling medium should be large enough so that the transmitted photons will not be absorbed in the glue layer. The glue should maintain its transmission properties during the lifetime of the CMS-experiment. Therefore it must have a negligible natural ageing and it must be radiation hard against gamma-, neutron- and proton-irradiation. The expected CMS lifetime dose and integrated fluence (barrel region, 10 years LHC) are 4.0 kGy and $2 \cdot 10^{13}$ neutrons/cm^2, respectively [3].

2 Sample preparation

Each test sample of the glue was prepared by glueing two plates of fused silica ($15 \times 12 \times 0.75$ mm^3) following the procedure indicated by the manufacturers. Distance rings (1.5 mm and 3.0 mm) were used to get a definite thickness of the glue. By this method one obtains a glue layer of 1.5 mm or 3.0 mm thickness sandwiched between two plates. A list of all tested glues is given in table 1[1)]. The transmission spectra of the specimen were recorded with a Perkin-Elmer Lambda 2 spectrophotometer.

Table 1: List of optical glues examined in the test.

glue	type	manufacturer/supplier	refractive index (at 589 nm)
Meltmount 1.704	thermoplastic	R. P. Cargille lab.	1.704
Meltmount 1.680	thermoplastic	R. P. Cargille lab.	1.680
Meltmount 1.662	thermoplastic	R. P. Cargille lab.	1.662
Meltmount 1.605	thermoplastic	R. P. Cargille lab.	1.605
Meltmount 1.582	thermoplastic	R. P. Cargille lab.	1.582
Naphrax	solvent based	R. P. Cargille lab.	1.68
BC 600	epoxy resin	Bicron	1.57
Dirax	natural resin	Northern Biological Supplies	1.60
OC 459	gel	Nye Lubricants Inc.	-

3 Absorption length and radiation hardness

3.1 Method:

The transmittance of glue specimen with a thicknesses of 1.5 mm and 3.0 mm was measured in the spectral range 300 nm$\leq \lambda \leq$ 1100 nm. The absorption length was calculated according to

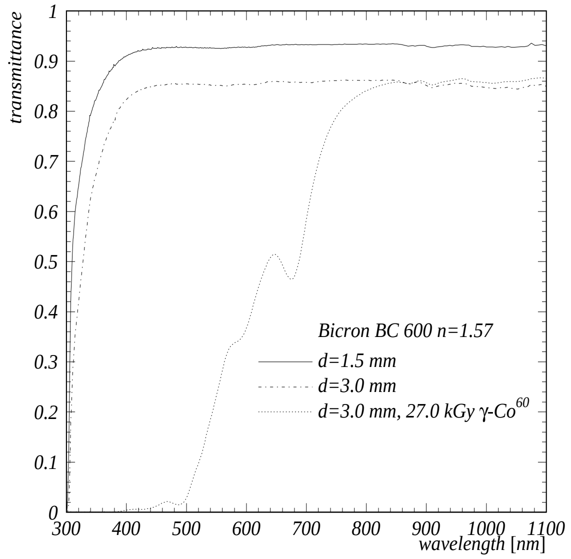
$$\Lambda = \frac{1.5\,mm}{ln\frac{T_{1.5}}{T_{3.0}}} \qquad (1)$$

The method is sensitive for values of $\Lambda < 100$ mm.

3.2 Results:

In a first step the glues listed in table 1 were irradiated with a dose of 27 kGy Co^{60} gammas. The irradiation was done at the Fraunhofer Institut für Naturwissenschaftlich-Technische Trendanalysen at Euskirchen (Germany). After this test, most of the glues were excluded from further investigation. As an example, figure 1 shows the transmission curves of BC 600, which is clearly not radiation hard, while figure 2 shows the curves for Dirax, which transmits efficiently only at wavelengths $\lambda > 600$ nm.

1) the refractive index at 589 nm is specified by manufacturer



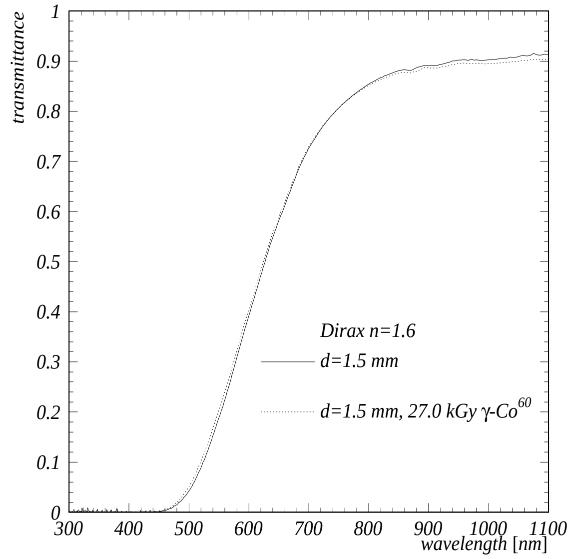
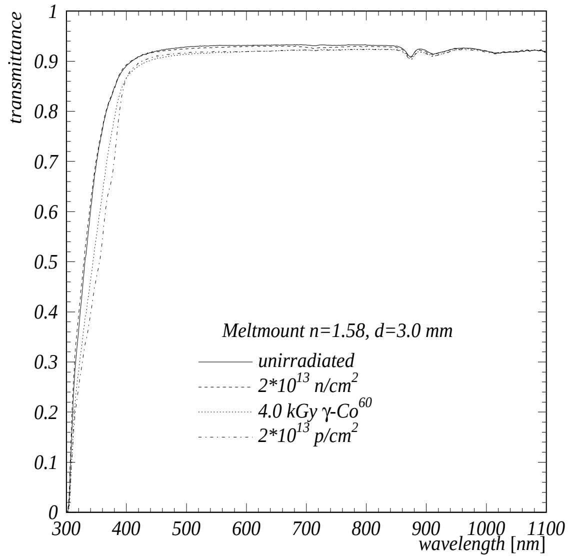


Figure 1: Transmission spectra of BC600 before and after irradiation (27 kGy Co^{60}).

Figure 2: Transmission spectra of Dirax before and after irradiation (27 kGy Co^{60}).



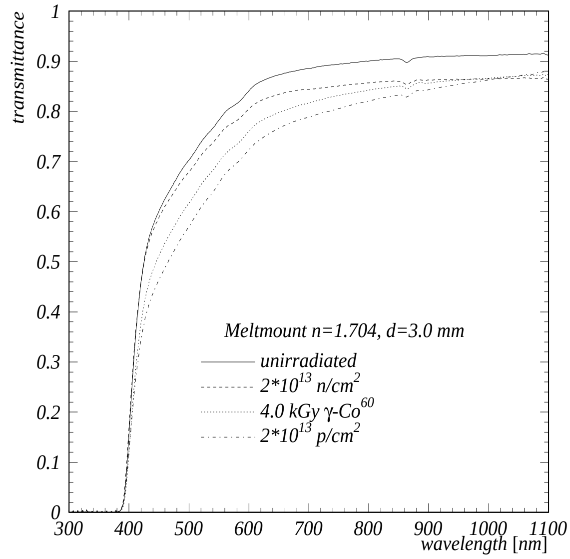


Figure 3: Transmission spectra of Meltmount 1.58 before and after gamma-, neutron- or proton-irradiation (4.0 kGy Co^{60}, $2 \cdot 10^{13} \frac{n}{cm^2}$, $2 \cdot 10^{13} \frac{p}{cm^2}$).

Figure 4: Transmission spectra of Meltmount 1.704 before and after gamma-, neutron- or proton-irradiation (4.0 kGy Co^{60}, $2 \cdot 10^{13} \frac{n}{cm^2}$, $2 \cdot 10^{13} \frac{p}{cm^2}$).

Only three glues (Meltmount 1.58, Meltmount 1.704 and Naphrax) showed reasonable radiation hardness and good transmittance for $\lambda > 400$ nm. In the next step specimen of these three glues were irradiated with gammas (4.0 kGy Co^{60}), neutrons ($2 \cdot 10^{13} \frac{n}{cm^2}$) and protons ($2 \cdot 10^{13} \frac{p}{cm^2}$). The gamma- and the neutron-irradiation were done at ENEA and the proton-irradiation at PSI. The results are given in table 2 and figures 3, 4 and 5.

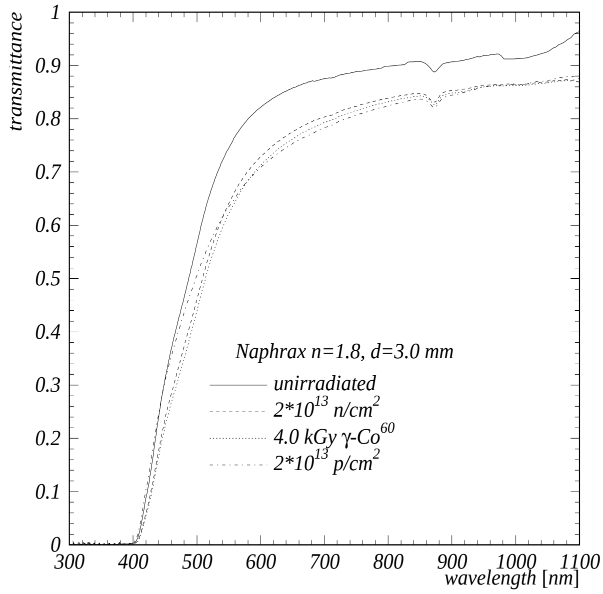


Figure 5: Transmission spectra of Naphrax before and after gamma-, neutron- or proton-irradiation (4.0 kGy Co^{60}, $2 \cdot 10^{13} \frac{n}{cm^2}$, $2 \cdot 10^{13} \frac{p}{cm^2}$).

Table 2: Absorption length Λ of the three optical glues at $\lambda = 420/500$ nm before and after gamma, neutron and proton irradiation.

glue	Λ (mm) at $\lambda = 420/500$ nm			
	unirradiated	4.0 kGy	$2 \cdot 10^{13} \frac{n}{cm^2}$	$2 \cdot 10^{13} \frac{p}{cm^2}$
Meltmount 1.582	$>$ 100 / $>$ 100	$>$ 100 / $>$ 100	$>$ 100 / $>$ 100	$>$ 100 / $>$ 100
Meltmount 1.704	4.7 / 12.1	4.1 / 10.5	4.7 / 11.7	3.2 / 6.7
Naphrax	1.2 / 5.2	0.9 / 2.9	0.9 / 3.5	1.2 / 4.6

4 Ageing test

4.1 Method:

The unirradiated specimen were heated to 80^0 in an atmosphere with 100% humidity for 12 hours and brought back to room conditions for another 12 hours. This cycle was performed repeatedly over a period of two months.

4.2 Results:

The resulting degradation of the absorption length is shown in figures 6, 7 and 8 and is summarized in table 3.

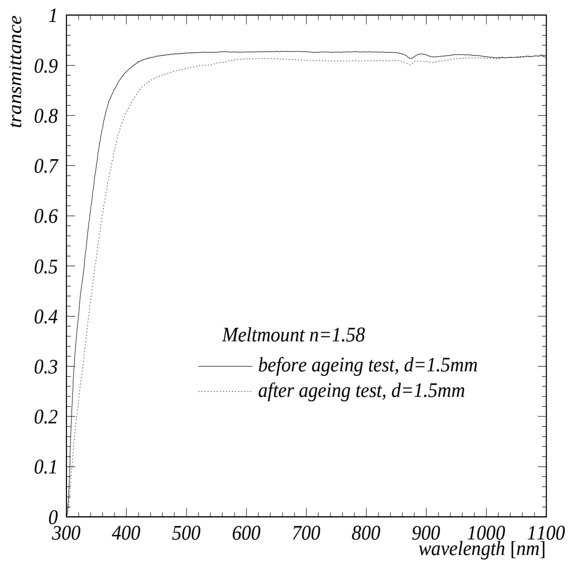


Figure 6: Transmission spectra of Meltmount 1.58 before and after ageing test.

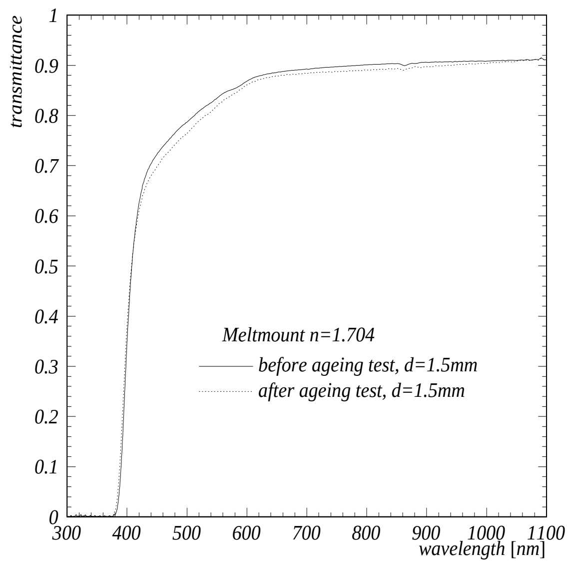


Figure 7: Transmission spectra of Meltmount 1.704 before and after ageing test.

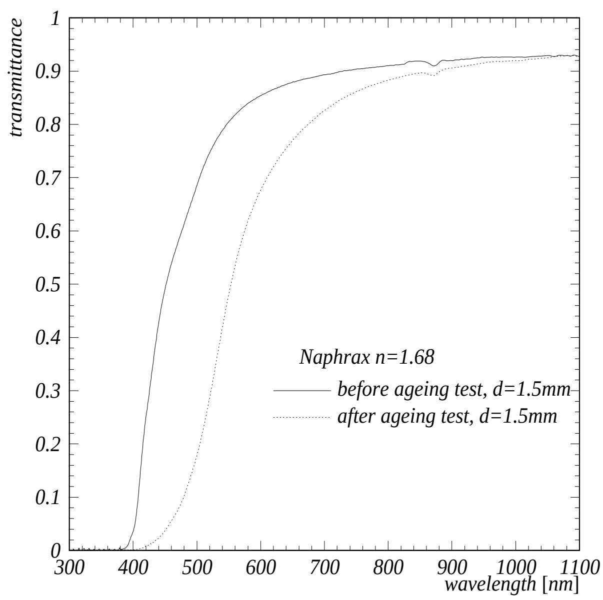


Figure 8: Transmission spectra of Naphrax before and after ageing test.

Table 3: Absorption length of the three optical glues at $\lambda = 420/500$ nm before and after ageing test.

glue	Λ (mm) at $\lambda = 420/500$ nm before	after ageing test
Meltmount 1.582	$>$ 100 / $>$ 100	24.4 / $>$ 100
Meltmount 1.704	4.7 / 12.1	4.2 / 12.0
Naphrax	1.2 / 5.2	0.3 / 2.0

5 APD test

5.1 Method:

The dark current of windowless Hamamatsu-APDs (S5345 prototype, Area:3×3 mm^2, Passivation: Si_3N_4) was measured at a gain of M=50 under room conditions to $I_D = 0.8$ nA. Then the APDs were directly covered with glue. In a first step the APDs were kept under room conditions over two weeks and the dark current was monitored. In a second step the diodes were cycled according to the ageing test described above. As a cross check an windowless APD without glue was also tested.

5.2 Results:

In the first step the dark current of the APDs didn't change ($I_D = 0.8$ nA at M=50).
In the second step the dark current of the APDs covered with the Meltmount glues didn't change after an ageing cycle of two months. APDs covered with Naphrax showed an increase from $I_D = 0.8$ nA to $I_D = 1.6$ nA. The APD without glue showed similar results as the Naphrax covered APD.

Acknowledgments

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[3] M. Huhtinen, *Radiation environment simulations for the CMS detector*, CMS TN 95-198.